

Modeling Fire Growth and Smoke Transport in the United States

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Abstract

In the United States, modeling of fire phenomena is done with both zone and field models. The applications are significantly different but there is overlap in the understanding and in most respects they are complementary.

1. Introduction

Fire phenomena include a large range of time and space scales. Time ranges from the picoseconds involved in molecular rearrangement and vibrational transitions to the hours needed for collapse of steel reinforced concrete barriers. Space scales range from microns in polymer connections to meters in construction. At present, it is not possible to include the entire range of phenomena in a comprehensive model of such processes. Therefore we use models which depend on a range of approximations. The approximations are appropriate to the situations of interest. At one end of the spectrum we have field models, another term for models which solve the Navier-Stokes equation in its full differential form. At the other end we have finite element models, generally utilizing only a few elements. These are usually referred to as zone models.

The primary purpose of zone type models is to predict the effect which a fire has on buildings and other structures, and their inhabitants. These models generally depend on confinement and hydrostatic stratification. They have the advantage of being very fast for complex buildings. The current practice includes three dimensional specification of fires, vertical and horizontal flow, and mechanical ventilation as well as natural or buoyancy driven flow. The most significant limitation is the assumption that there is no velocity field within a zone.

The other extreme is the concept of field models where a complete set of mass, momentum and energy equations is solved for many grid points. This allows one to map the velocity field in great detail. Generally, the limitation of confinement and stratification do not apply to these models, although there is a corresponding problem in specification of the boundary conditions. Current practice encompasses single step combustion, both large (city size) and small (candle size) volumes. The primary limitation is the large number of grid points necessary to model a particular scenario.

The purpose of modeling is two-fold: a) to answer specific questions; b) to test

ones understanding of a particular phenomenon. It is important to choose the appropriate tool to address either of these goals. At present the two types of models are distinct. However, as will be discussed later in these proceedings, the concepts are beginning to merge as we move closer to a more general model of fire growth and smoke transport. In effect we are beginning to merge the large and small space scales. We can now examine the long time scales. The facet of modeling which still eludes us is the short time scale involved in chemical kinetics.

ZONE MODELS

The most common type of models utilized to study building fires are referred to as zone models. A zone model is a particular implementation of the class of numerical models known as finite element models. The motivation for using such models in preference to a complete implementation of the Navier Stokes-equation is the great difficulty in obtaining solutions of the latter in realistic fire scenarios. One uses only a few elements, or zones, per compartment, and thus can apply the technique to many compartments. A more complete description of zone models is given elsewhere^{1,2,3,4}. This type of model works well so long as detailed flow field predictions are not needed.

Most of the effort in the United States is involved is using zone models for predictive purposes. The primary model is FAST, and is used through HAZARD I, the primary fire hazard assessment methodology used in the US. Other models in use include CFAST, BRI2 (Tanaka), Compbrn, FIRST, and LAVent. CFAST and BRI2 will be discussed at this meeting. Another model, which is similar in nature but not a true zone type model, is FPETool. Rather it is a collection of engineering approximations whose purpose is to estimate the outcome of various fire scenarios.

Over the past two years, the only zone model which has been developed extensively is CFAST. It will be the underpinning for the new version of HAZARD I. We are also promoting its use as a platform for cooperation among the various organizations involved in modeling fire. This is a result of the extensive effort that has been put into assuring its reliability and robustness.

Zone models are most often used for fire scenario reconstruction⁵. However, as is evident from the papers by Bukowski, Kura, Tanaka and others, these types of models are gaining widespread acceptance in the proactive role of better design of buildings.

FIELD MODELS

The development of a field model is a long term undertaking. There exist models which have been developed commercially and are being modified and used, as well as a few models which have been constructed within laboratories in the United States. In the former category are Phoenix, which is used at the Factory Mutual Research Corporation, Flow3D, used at the National Institute of Standards and

Technology, and Fluent, used by Forensic Technologies in Annapolis Maryland. There are two versions of the type developed within laboratories, one developed at the Naval Research Laboratory by Boris and Oran⁶ and the other at NIST, developed by Baum and Rehm⁷. There are many models of this type used for specialized research in combustion, but they are not the subject of this presentation.

This type of model is very computational intensive. For this reason it is generally used only when details of the flow are needed. Such need occurs for example in calculating the movement of smoke in an atrium, or the precise flow field around a sprinkler head. For example, if one wanted to use recessed sprinkler heads or smoke detectors, a zone model with a ceiling jet algorithm would not be sufficient.

Model development is taking place at NIST and NRL. Modification efforts on commercial codes are underway at Factory Mutual, the University of California (Berkeley), NIST, Forensic Technologies and elsewhere. The work at Factory Mutual is to look at droplet evaporation, and flow field interaction from sprays induced by sprinklers. At the University of California, Pagni and coworkers are using the NIST model to study large fires such as the Oakland Hills conflagration⁸. At NIST, we are using both a commercial model (Flow3D) to study detector activation, and the Baum and Rehm model to look at large scale plumes and the interaction of combustion with the flow field. The work at Forensic Technologies is in the area of fire scenario reconstruction.

SUMMARY

A lot of exciting work has taken place over the past two years, and the rate of improvements is accelerating. We are now in a position to develop a synergism between the zone models and the field models. In particular, as will be discussed, we are beginning to utilize some of the simpler field concepts in the zone models. On top of this, the chance to use a field model to either validate a zone model, or develop an algorithm to be incorporated into a zone model will promote the general use of models.

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